



Integrity of benthic macroinvertebrate communities in Fort Necessity National Battlefield and Friendship Hill National Historic Site

Eastern Rivers and Mountains Network 2009 summary report

Natural Resource Data Series NPS/ERMN/NRDS—2010/028



ON THE COVER

Dublin Run at Friendship Hill National Historic Site.
Photograph by: Caleb Tzilkowski.

Integrity of benthic macroinvertebrate communities in Fort Necessity National Battlefield and Friendship Hill National Historic Site

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Abstract

During 2008, the Eastern Rivers and Mountains Network (ERMN) of the National Park Service (NPS) began monitoring benthic macroinvertebrate (BMI) communities in wadeable streams throughout its nine parks. This report provides preliminary results of sampling during 2008–2009 at three targeted (non-random) sites at Fort Necessity National Battlefield (FONE) and two targeted sites at Friendship Hill National Historic Site (FRHI). In addition to BMI samples, core water quality data (i.e., temperature, dissolved oxygen, pH, and specific conductance) were collected and reach-scale habitat was characterized.

Abandoned mine drainage to Ice Pond Run has been well documented; thus, it was not a surprise that water in that stream had exceptionally high specific conductance (928 $\mu\text{S}/\text{cm}$) and extremely low pH (2.63). At the unnamed tributary (UNT) to Scotts Run (Picnic Loop) measures of specific conductance (46.1 $\mu\text{S}/\text{cm}$) and pH (5.76) were relatively low, whereas those parameters were typical of similarly sized Pennsylvania streams at Dublin Run and Great Meadows Run. Due to habitat conditions (i.e., low flow, silt substrate), samples could not be collected effectively from the UNT to Great Meadows Run. Similar conditions existed in Great Meadows Run, and although a sample was collected at that site, the sample is also considered to be of limited value. Proposed alternative strategies (i.e., artificial samplers) are described to sample those streams. Benthic macroinvertebrate communities at four stream sites sampled in FONE and FRHI had Macroinvertebrate Biotic Integrity Index values that ranged from 14.29 (Ice Pond Run) to 51.4 (UNT to Scotts Run [Picnic Loop]).

Given that this report represented the first year of data collection, there were few inferences or management recommendations that could be confidently made. Biological communities (including BMI) can vary through time due to a range of naturally occurring biotic phenomena (e.g., interspecific competition, predation) and abiotic disturbances (severe drought, floods). It will take several years to determine the degree to which BMI communities naturally vary throughout FONE, FRHI, and the rest of the ERMN. Once natural variability of BMI communities is quantified, we will be in a better position to make inferences regarding the relative condition of sampled streams.

Introduction

During 2008, the Eastern Rivers and Mountains Network (ERMN) of the National Park Service (NPS) began monitoring benthic macroinvertebrate (BMI) communities in wadeable streams throughout its nine parks. This monitoring effort is a component of the ERMN Vital Signs monitoring program (Marshall and Piekielek 2007) as part of the nationwide NPS Inventory and Monitoring Program (Fancy et al. 2009).

One of the primary objectives of the ecological monitoring program in the ERMN is to evaluate status and trends in the condition of tributary watersheds flowing into and through member parks. Watershed condition is evaluated using measures of ecosystem integrity, including streamside bird species and communities (Mattsson and Marshall 2009), forest structure and composition (Perles et al. 2009), stream-dwelling benthic macroinvertebrates (Tzilkowski et al. 2009), stream chemistry, and watershed land use, type, and configuration (Marshall and Piekielek 2007). A primary purpose of the benthic macroinvertebrate monitoring protocol is to support the antidegradation or restoration of ERMN aquatic communities and their habitat (including water quality) by communicating monitoring program results to appropriate regulatory state and federal agencies.

Benthic macroinvertebrates are aquatic invertebrate animals larger than microscopic size that live on or within the stream bottom (benthos), and because they are a vital component of all functioning stream ecosystems, they are often used as indicators of ecosystem integrity. Types of BMI that are commonly used for water quality assessment include arthropods (insects, arachnids, and crustaceans), worms, clams, and snails. In addition to being instrumental to nutrient and carbon dynamics, BMI are an important link between basal resources (e.g., algae and detritus) and higher trophic levels (e.g., fish and birds) in stream food webs. Because BMI have been by far the most commonly used group for biological monitoring of aquatic ecosystems (Carter and Resh 2001), many metrics have been evaluated with respect to natural variation and responses to various sources of human-induced degradation. Given the proven ability to derive ecosystem integrity based on measures of BMI assemblage structure and composition, combined with the relatively low cost to sample, BMI are almost certainly the single best biological group to assess and monitor the ecological integrity of small and mid-sized streams.

At the time this report was prepared, the BMI monitoring protocol (Tzilkowski et al. 2009) had been developed, written, and received internal peer review, but had not undergone the final peer review process. This report was intended to provide preliminary results to the natural resource manager at Fort Necessity National Battlefield (FONE) and Friendship Hill National Historic Site (FRHI). The preliminary nature of data presented in this report should be considered prior to its use or dissemination.

Methods

Although a brief overview of the BMI monitoring methods is provided here, a detailed rationale of the sampling design and methods, in addition to Standard Operating Procedures, are provided in the BMI Monitoring Protocol (Tzilkowski et al. 2009). Much of this protocol is based on protocols developed by the U.S. Geological Survey ([USGS] Moulton et al. 2000, Moulton et al. 2002) and Bowles et al. (2006) because those protocols and programs have already undergone considerable evaluation and revision. We modified those protocols to fit the character of ERMN parks and anticipated monitoring resources.

Site Selection

There are two types of sampling sites in the BMI Monitoring Program – probabilistic (i.e., stratified-random) sites and non-random “targeted” sites. The probability-based design was not used at FONE or FRHI due to the (1) relatively small size of the parks and (2) few stream segments that could be included in a random design. Instead, three targeted sites at FONE (Figure 1) and two targeted sites at FRHI (Figure 2) were chosen in consultation with Connie Ranson, the Natural Resource Specialist at the parks. Justification for selecting the FONE sites was as follows. The sites on Great Meadows Run and on the unnamed tributary (UNT) to Great Meadows Run were chosen because those two streams drain the majority of the main park unit, whereas the UNT to Scotts Run (Picnic Loop) was chosen to be collocated with the Streamside Bird monitoring (Mattsson and Marshall 2009) point located there. There is also a Streamside Bird Monitoring point on the UNT to Great Meadows Run, but not on the Great Meadows Run mainstem. The two sites at FRHI were selected because the streams that they are located on (Dublin Run and Ice Pond Run) drain the majority of the park; moreover, there are Streamside Bird Monitoring points on both streams.

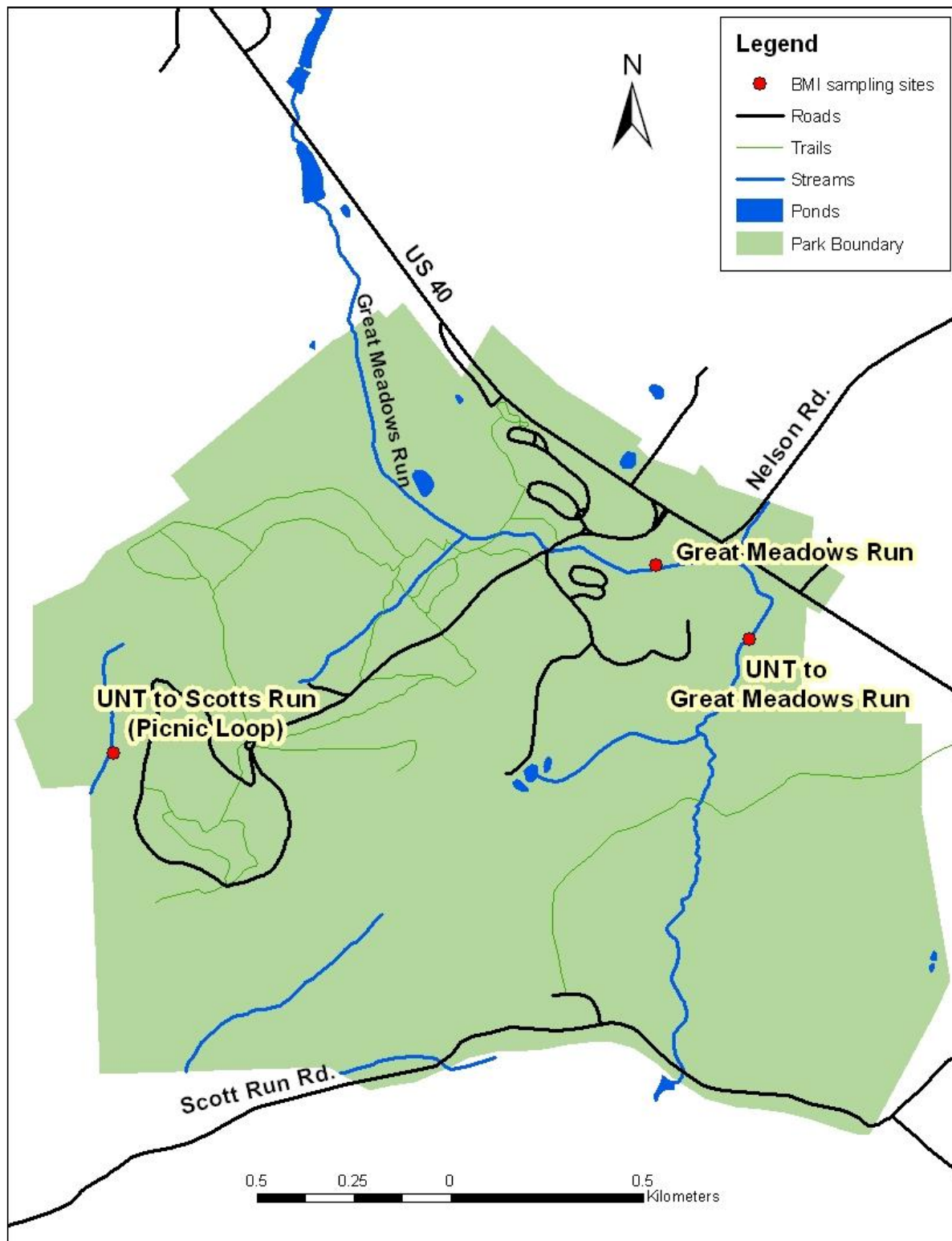


Figure 1. Benthic macroinvertebrate sampling sites at Fort Necessity National Battlefield. UNT = unnamed tributary.

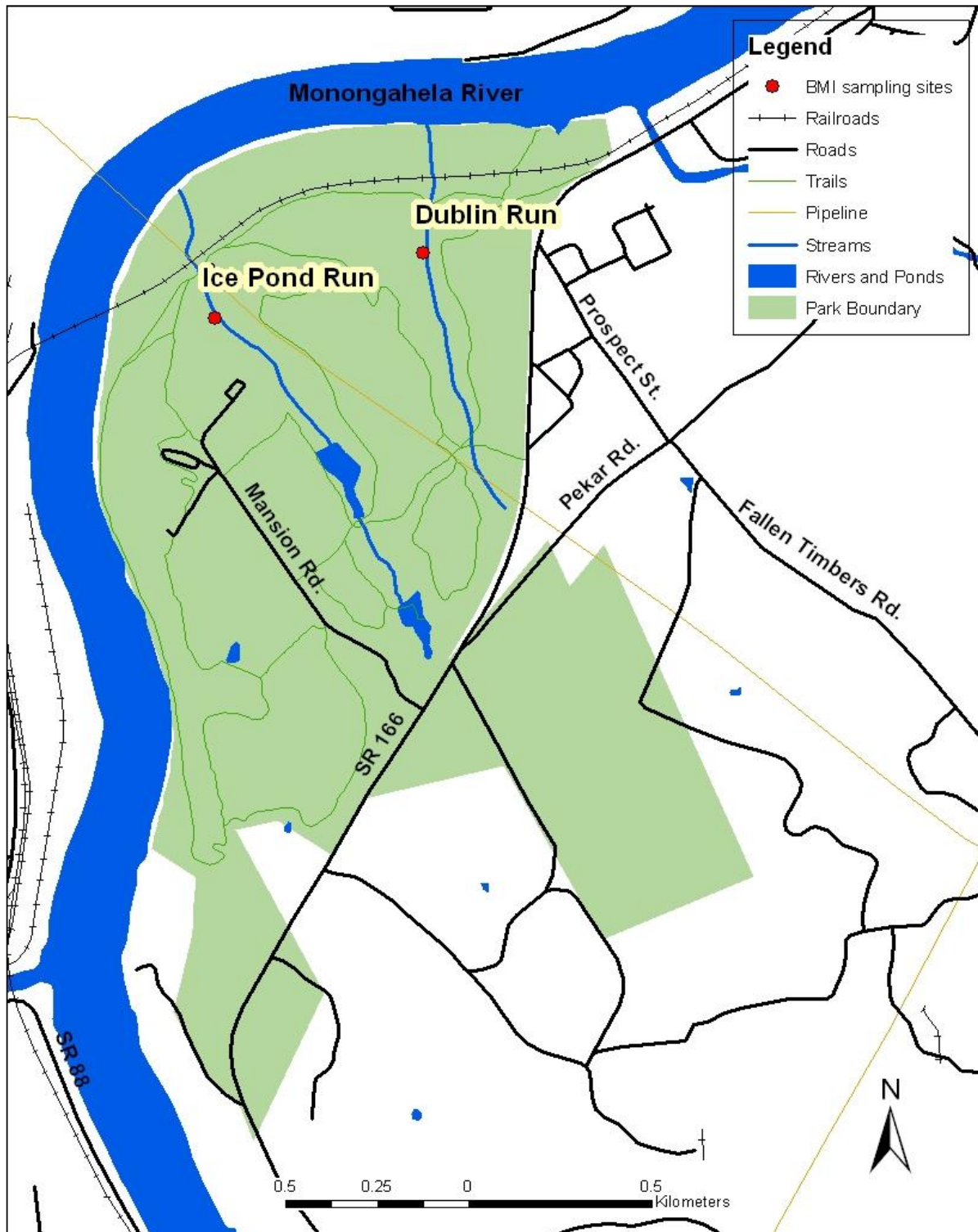


Figure 2. Benthic macroinvertebrate sampling sites at Friendship Hill National Historic Site.

Field Methods

The sampling unit for the BMI monitoring program is the stream reach. For the ERMN program, the reach is defined as a longitudinal section of stream chosen to represent a uniform set of physical, chemical, and biological conditions within a stream segment. The length of sampled reaches differs among watersheds, but their length is proportional (i.e., 40 ×) to stream width. Minimum and maximum reach lengths are 150 m and 500 m, respectively.

Streams at FONE and FRHI were sampled during the fall (2008) and spring (2009). The ERMN method for collecting BMI from most ERMN streams is termed semi-quantitative, richest-targeted habitat sampling (RTH, Moulton et al. 2002), which is a type of disturbance-removal sampling. Although similar to more common kick sampling methods, RTH sampling calls for consistent and thorough collection of BMI from a fixed area; thus, it is considered a more precise method and allows for estimation of stream productivity unlike many other sampling methods. Many BMI disturbance-sampling methods are qualitative (not quantitative) and are comparatively inconsistent because there is no measurement of sampling area – instead, those methods usually rely on a timed sampling effort. For the RTH method, five discrete samples are collected from riffles throughout the reach and are ultimately composited into a single homogenous sample. Ideally, discrete samples are taken from different riffles, but if fewer than five riffles are present, samples may be taken from the same riffle. Physical conditions (i.e., depth, flow, and substrate) are recorded at each sampling location and should be as similar as possible among replicates. Sampling is conducted by defining a 0.25 m² sampling area with a template and then disturbing substrate within that area so that BMI are dislodged and then drift into a net placed downstream of the sampling area. The composited samples result in 1.25 m² of sampled area at each site.

Although the RTH method is ideally suited for most streams in the ERMN, it did not work well at two FONE streams (Great Meadows Run and UNT to Great Meadows Run). The RTH method is best suited for sampling medium- to high-gradient streams with abundant riffles and cobble substrate. Great Meadows Run and UNT to Great Meadows Run did not have adequate riffle habitat, probably because: 1) those streams were naturally relatively low-gradient streams; and 2) their channels and floodplains were historically manipulated. We think that those manipulations have resulted in stream channels with incised banks, few riffles, and a mixture of sand and silt substrate. Due to the lack of suitable habitat, only Great Meadows Run has been sampled to date and results from that sample are considered to be of marginal value. That sample was collected during fall 2008. At the same time, we attempted to sample UNT to Great Meadows Run but were unsuccessful due to low (nearly nonexistent) stream flows. We tried again to sample both streams during spring 2009 because it was thought that higher stream flows would result in a greater abundance of appropriate habitat. Although flows were higher, sampling was still difficult due to lack of appropriate substrate; therefore, we will deploy multiplates (artificial substrate sampling devices) in the future for five weeks during March and April. Multiplates provide substrate for BMI colonization for a fixed exposure period, after which the sampler is retrieved and the attached organisms are harvested. Using multiplates allows comparison of results from different locations and times by providing uniformity of substrate type, depth, and exposure duration (Bode et al. 2002). It should be noted that BMI that colonize multiplates are influenced more by water quality than by stream bottom conditions; consequently, comparisons among multiplate samples and other sampling gear (e.g., kick nets) should be done with caution.

In addition to BMI samples, core water quality data (i.e., temperature, dissolved oxygen, pH, and specific conductance) were collected and reach-scale habitat was characterized using the U.S. Environmental Protection Agency (USEPA) rapid bioassessment method (Barbour et al. 1999). Samples were processed in the field by using an elutriation method to remove mineral materials and large organic matter (e.g., whole leaves and sticks). Samples were preserved in 95% ethanol, packed carefully, and transported back to the laboratory for processing and identification.

Laboratory Methods

Laboratory methods for processing samples in the ERMN BMI Program rely a great deal on procedures developed by the USGS (Moulton et al. 2000). A fixed-count subsample of $300 \pm 20\%$ individuals are sorted and identified from each sample. The relatively large subsample size yields data that meets quality standards (i.e. precision and accuracy) required by most monitoring programs; however, processing and identifying additional individuals (> 300) typically does not yield enough additional information to justify the added effort (Moulton et al. 2000). Generally, BMI were identified to genus using standard dichotomous keys, but some groups (e.g., Chironomidae, Oligochaeta) were identified to coarser taxonomic levels. Microsoft Access 2007 is the primary software used for storing and managing ERMN BMI and stream habitat data, whereas the Invertebrate Data Analysis System (IDAS *version 5*, U.S. Geological Survey, Raleigh, NC) was used for resolving taxonomic ambiguity issues and calculating metrics that describe the structure and diversity of BMI communities.

Data Analysis

We calculated all BMI community metrics with IDAS and calculated the Macroinvertebrate Biotic Integrity Index ([MBII] Klemm et al. 2003) using Microsoft Excel 2007. The MBII was developed by the USEPA Environmental Monitoring and Assessment Program (EMAP) and was ultimately used for the USEPA's Wadeable Stream Assessment (WSA, USEPA 2006, Herlihy et al. 2008).

The rationale behind biotic integrity indices is that a suite of metrics that represent community structure, pollution tolerance, functional feeding groups and habitat occurrences, life history strategies, disease, and density provide insight into how biological communities respond to different natural and anthropogenic stressors (Klemm et al. 2003). A common stream bioassessment practice is to compare BMI community metrics from candidate streams to the same metrics from reference streams. Reference streams are "least-disturbed," similarly sized streams within comparable geographic and geologic settings that provide an estimate of least-impaired stream communities. Departure of the sampled BMI community from expected BMI community composition (i.e., reference streams) serves as a measure of stream impairment. The MBII is one such index that uses reference streams to assess stream impairment.

The MBII was chosen for use in the ERMN because it was developed for upland and lowland streams dominated by riffle habitat in the Mid-Atlantic Highlands Region (MAHR). Moreover, the MBII was based on a large dataset of 574 wadeable stream reaches and was thoroughly tested. The MBII is a broadly applicable measure of stream impairment because it is based on several factors that affect aquatic communities throughout the MAHR. Impaired and reference streams for the MBII were identified by Klemm et al. (2003) using water chemistry, qualitative habitat, and minimum organism count criteria. Impaired reaches were defined by meeting any one of the following criteria: pH < 5 , chloride $> 1000 \mu\text{eq/L}$, sulfate $> 1000 \mu\text{g/L}$, total

phosphorous >100 µg/L, total nitrogen >5000 µg/L, or a mean qualitative habitat score <10 (of a possible 20). Reference reaches met all of the following criteria (Klemm et al. 2003): sulfate <400 µg/L, Acid Neutralizing Capacity (ANC) >50 µeq/L, chloride <100 µeq/L, total phosphorous <20 µg/L, total nitrogen <750 µg/L, mean qualitative habitat score >15, and at least 150 organisms.

The MBII uses seven metrics selected from the 100 that are commonly used by governmental agencies throughout the MAHR. The metrics chosen were those that performed best in terms of range, precision, responsiveness to various human-induced disturbances, relationship to catchment area, and redundancy (Table 1; Klemm et al. 2003). Most MBII metrics are counts or proportions of taxa in the community that are characterized as tolerant or intolerant to human perturbations; however, one of the metrics (Macroinvertebrate Tolerance Index; MTI) is more complex because it incorporates values (0–10) for each taxon with respect to pollution tolerance, weighted by taxon abundance, and results in higher scores as the proportion of taxa tolerant to general pollution increases (Klemm et al. 2003). Pollution Tolerance Values (PTV) incorporated in the MTI were average tolerances to “various types of stressors” (Klemm et al. 2002).

Table 1. Macroinvertebrate Biotic Integrity Index metric descriptions and their directions of response to increasing human perturbation (Response) from Klemm et al. (2003).

Metric	Description	Response
Ephemeroptera richness	Number of Ephemeroptera (mayfly) taxa	Decrease
Plecoptera richness	Number of Plecoptera (stonefly) taxa	Decrease
Trichoptera richness	Number of Trichoptera (caddisfly) taxa	Decrease
Collector-filterer richness	Number of taxa with a collecting or filtering-feeding strategy	Decrease
Percent non-insect individuals	Percent of individuals that are not insects	Increase
Macroinvertebrate Tolerance Index	$\sum_i p_i t_i$, where p_i is the proportion of individuals in taxon i and t_i is the pollution tolerance value (PTV) for general pollution	Increase
Percent five dominant taxa	Percentage of individuals in the five numerically dominant taxa	Increase

We also present three other commonly used BMI community metrics (taxa richness, Shannon's Diversity and Evenness) for comparison because they are likely to be familiar to most readers of this report. Taxa richness was the combined number of unique taxa (usually genera). Shannon's diversity and evenness were calculated with IDAS using formulae provided by Brower and Zar (1984), which were:

Shannon's Diversity (H'): information theory-based index that measures the "uncertainty" of a taxon selected at random from the community. High diversity is associated with high uncertainty and low diversity with low uncertainty. This index is the equivalent of the Brillouin's diversity index, but it is intended for use when the abundance data come from a random sample of the community or subcommunity.

$$H' = (N \log_{10} N - \sum n \log_{10} n) / N$$

Shannon's Evenness (J'): ratio of the observed Shannon diversity to the maximum possible diversity (that is, diversity when individuals are distributed as evenly as possible among the species). Like the Shannon diversity index, this measure is intended to be used when the abundance data come from a random sample or the community or subcommunity

$$J' = H' / H_{\max}' \text{ where } H_{\max}' = \log_{10} S$$

Abbreviations used in formulae: S = number of taxa in sample, n = abundance of an individual taxon, N = total number of individuals in sample.

Results

Benthic Macroinvertebrate Communities

Benthic macroinvertebrate communities throughout FONE and FRHI streams had MBII values that ranged from 9.41 (Great Meadows Run) to 51.4 (UNT to Scotts Run, Picnic Loop; Figure 3). Because BMI sampling at FONE and FRHI will be conducted during the spring in the future, discussion of the fall 2008 results is limited to the Great Meadows Run sample because that stream was not sampled in spring 2009. Dublin Run and Ice Pond Run were the only streams to be sampled in both seasons and results were remarkably similar among seasons. Detailed results are available upon request for fall 2008 sampling, but as an illustration of their similarity, MBII scores for the seasons (fall, spring) were: Dublin Run (33.31, 30.92) and Ice Pond Run (14.29, 14.29).

Based on MBII thresholds for the Southern Appalachians Ecoregion (Herlihy et al. 2008), only one site (UNT to Scotts Run, Picnic Loop) was considered to be in the “Good” condition class, but that score was marginally above the “Fair” threshold (i.e., MBII = 51.0). All remaining sites that were sampled were in the “Poor” condition class; however, as mentioned in the methods section, physical characteristics of Great Meadows Run yielded a sample that probably was not representative of the BMI community in that stream. We do not think that Great Meadows Run was in poorer condition than Ice Pond Run but chose to provide results here to illustrate the difficulties encountered by the physical characteristics of that stream. Low stream flow and lack of riffle habitat probably led to the extremely low estimate of BMI density in Great Meadows Run (106 m^{-2} ; Figure 4). Again, due to similar, but even less ideal conditions at UNT to Great Meadows Run, samples were not collected there.

The following results do not include the sample from Great Meadows Run because we do not consider that sample to be comparable to the other samples. Among FONE and FRHI streams, total taxa richness ranged from 7 (Ice Pond Run) to 39 (UNT to Scotts Run [Picnic Loop]; Table 2). In addition to having the lowest taxa richness, Ice Pond Run ranked last for the remaining MBII metrics, which was most notably reflected by the exceptionally low Shannon Diversity (0.08) and Evenness (0.09) measures calculated for that site. Given the calculated MBII values, it was not surprising that UNT to Scotts Run (Picnic Loop) ranked highest for all of the metrics that comprise the MBII.

Water Quality

Physical and chemical characteristics often vary markedly, both daily and annually. Although there are limitations to point-in-time characterizations of core water quality parameters, these measures can be helpful when evaluating patterns in biological data; moreover, extreme changes to these parameters can sometimes be detected with point-in-time samples. Water in Ice Pond Run had exceptionally high specific conductance ($928 \mu\text{S}/\text{cm}$) and extremely low pH (2.63; Figure 5). At UNT to Scotts Run (Picnic Loop) measures of specific conductance ($46.1 \mu\text{S}/\text{cm}$) and pH (5.76) were relatively low, whereas at Dublin Run and Great Meadows Run, those parameters were typical of 2nd order streams with comparable geology throughout the region. Water temperature at FONE and FRHI sites was also typical of Pennsylvania streams, whereas dissolved oxygen concentrations were lower than expected (Figure 6); however, we suspected that there was a faulty membrane on the DO meter while sampling FONE and FRHI during spring 2009. We were unable to replace the membrane until returning to the laboratory and did not return to either park after replacing it. We now have access to “backup” equipment which will prevent similar occurrences in the future.

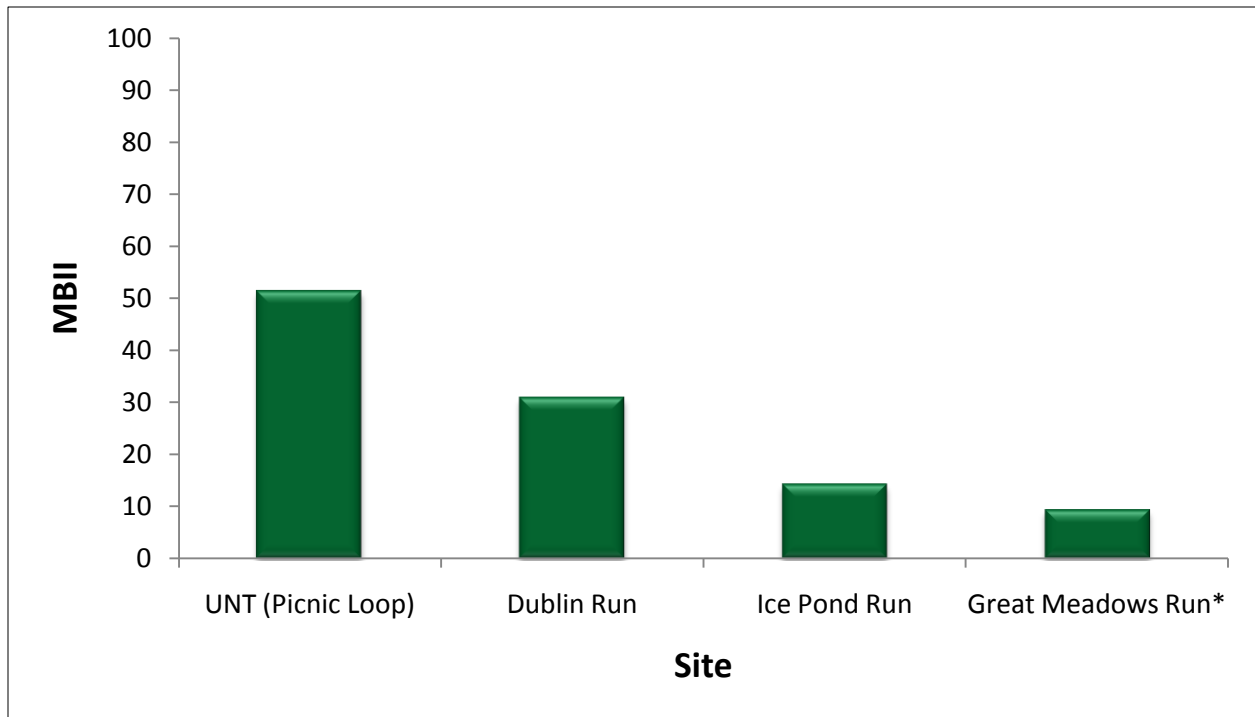


Figure 3. Macroinvertebrate Biotic Integrity Index ([MBII] Klemm et al. 2003) values for benthic macroinvertebrate samples collected throughout Fort Necessity National Battlefield and Friendship Hill National Historic Site. *The low MBII value calculated for Great Meadows Run was likely partly attributable to poor sampling effectiveness.

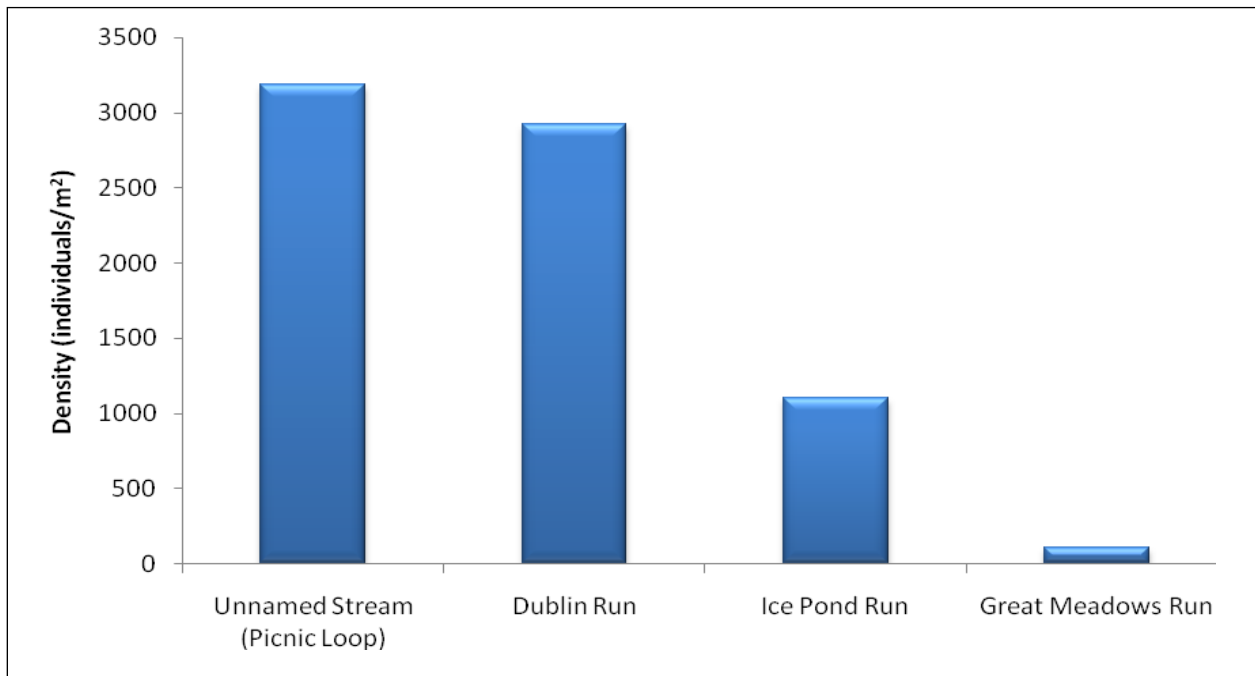


Figure 4. Density of benthic macroinvertebrates collected at sampling sites throughout Fort Necessity National Battlefield and Friendship Hill National Historic Site.

Table 2. Summary metrics and multimetric indices for benthic macroinvertebrate communities sampled from Fort Necessity National Battlefield and Friendship Hill National Historic Site. Direction of metric or index response to increasing stream ecosystem integrity are denoted parenthetically by + or -. Richness metrics included total taxa richness (Total), and richness of Ephemeroptera (E), Plecoptera (P), Trichoptera (T), and Collector or Filter feeders (C-F). Proportional metrics included the percent of individuals in samples that were non-insect taxa (%Non-insects) or that comprised the combined five dominant taxa in the community (%5 dominant). Indices were the Macroinvertebrate Tolerance Index (MTI) and the Macroinvertebrate Biotic Integrity Index (MBII).

Stream	Date	Richness (+)					Proportional (-)		Shannon (+)		Indices	
		Total	E	P	T	C-F	%Non-insects	%5 dominant	Diversity	Evenness	MTI (-)	MBII (+)
Dublin Run	11/03/2008	23	3	2	5	8	3.60	73.38	1.01	0.74	4.19	33.3
Dublin Run	4/15/2009	27	4	4	6	8	5.40	78.63	0.91	0.63	4.48	30.9
Ice Pond Run	11/03/2008	4	0	0	0	1	0.00	100	0.02	0.03	5.99	14.3
Ice Pond Run	4/15/2009	7	0	0	0	2	0.00	99.85	0.08	0.09	6.04	14.3
Great Meadows Run	11/04/2008	15	1	2	2	4	9.09	87.88	0.65	0.55	5.65	9.4
UNT (Picnic Loop)	4/16/2009	39	9	6	6	12	5.32	61.16	1.19	0.75	4.28	51.4

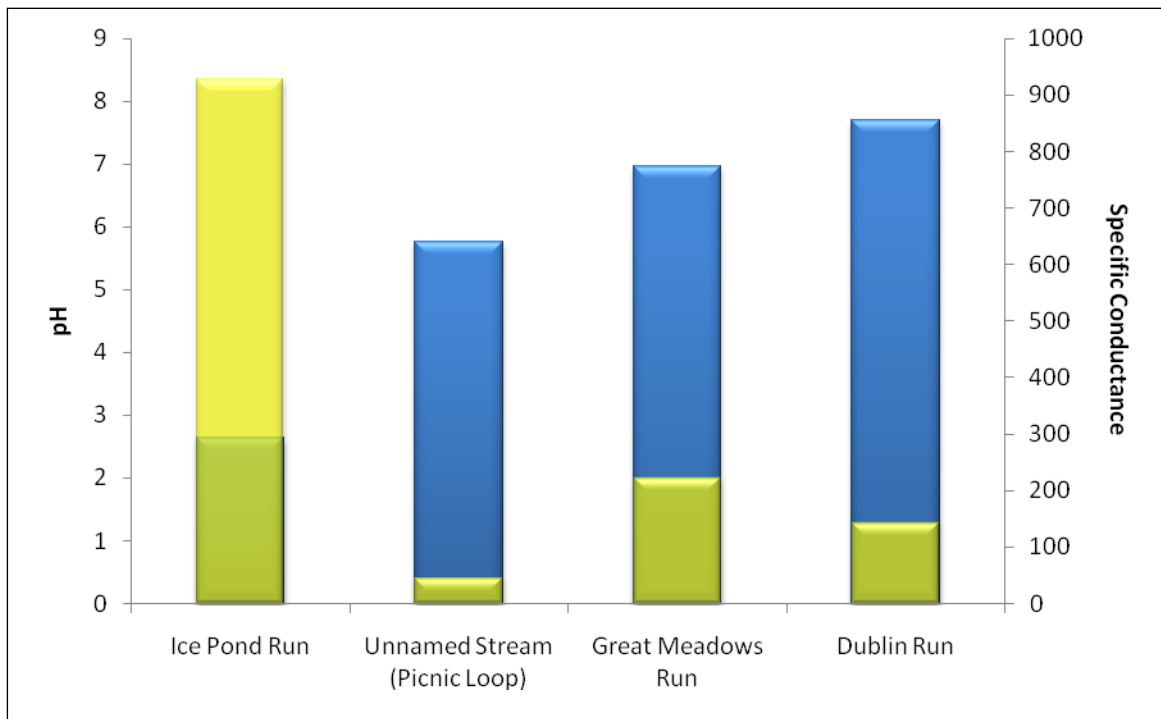


Figure 5. pH (blue bars) and specific conductance (yellow bars) of water at sampling sites throughout Fort Necessity National Battlefield and Friendship Hill National Historic Site.

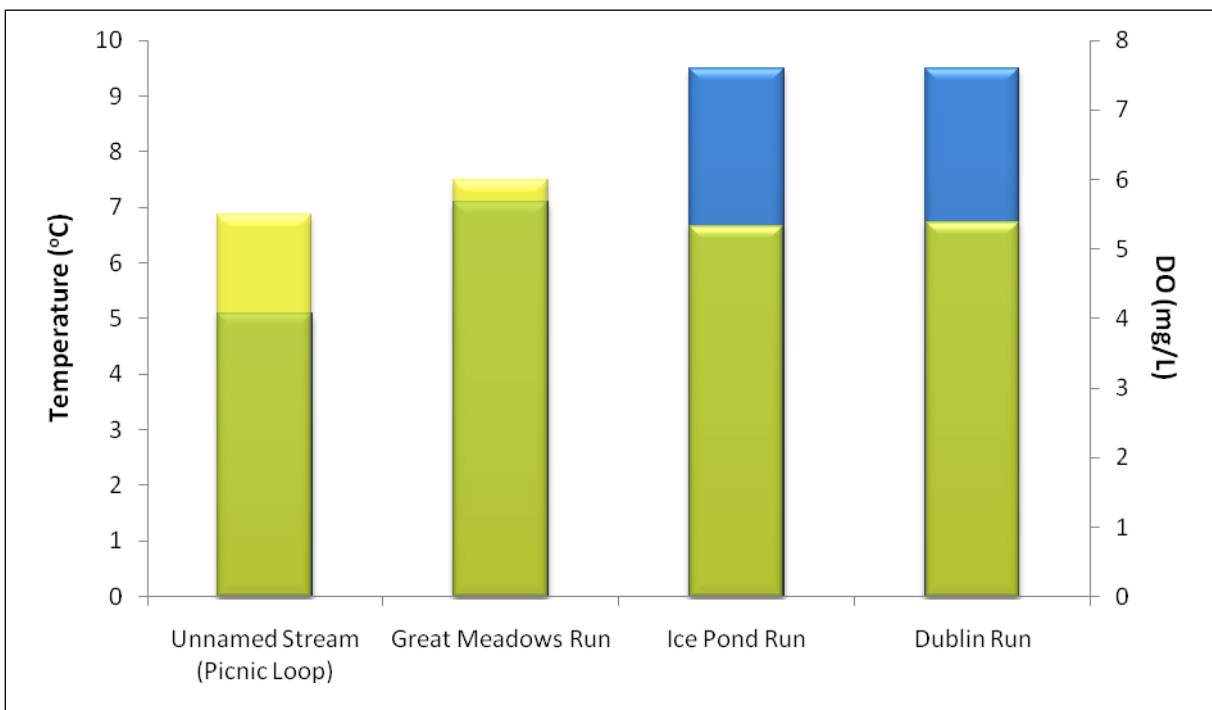


Figure 6. Temperature (blue bars) and dissolved oxygen concentration (yellow bars) of water at sampling sites throughout Fort Necessity National Battlefield and Friendship Hill National Historic Site.

Discussion

This report summarized results from the first sampling season of the ERMN BMI monitoring program at FONE and FRHI. The effort was mostly successful in that it provided quality data for many of the chosen sites. As discussed previously, habitat at two FONE sites prevented them from being sampled effectively, but alternative methods (i.e., multiplates) will be used to overcome those difficulties in the future. At sites where sampling was conducted, all components of the protocol worked well. This was not surprising because the protocol was based largely on widely used USGS protocols. The primary challenge to interpreting the data (as discussed in the methods section) was that, because the ERMN protocol did not precisely follow all other state or regional protocols, comparing our data with other efforts included qualifications.

Given that this report represented the first year of data collection, there were few inferences or management recommendations that could be confidently made. Biological communities (including BMI) can vary through time due to a range of naturally occurring biotic phenomena (e.g., interspecific competition, predation) and abiotic disturbances (severe drought, floods). It will take several years to determine the degree to which BMI communities naturally vary throughout FONE, FRHI, and the rest of the ERMN. Once natural variability of BMI communities is quantified, we will be in a better position to make inferences regarding the relative condition of sampled streams.

With each future sampling season, the ERMN BMI monitoring program will be refined and improved. It is anticipated that metrics and indices will be calibrated so that more precise and accurate comparisons can be made among FONE and FRHI streams and streams throughout the region. In addition to calibrating the MBII and its constituent metrics, we will add other measures of stream integrity as more data are gathered. For example, another meaningful way to express BMI community condition is with Observed/Expected Indices that estimate the number of taxa (e.g., genera) that have been lost (i.e., extirpated) from a given stream (Yuan 2008). To use these methods, the expected number of taxa for a given stream type must be established from the least disturbed streams in the region. This process will likely begin after next season when assessments regarding natural variability of BMI communities can be at least coarsely made. During the next several years, we plan to cooperate with researchers from the Pennsylvania State University to standardize ERMN data to stream condition thresholds established during the WSA. That effort will allow more confident comparisons to be made between ERMN streams and similar streams throughout the ecoregion.

As mentioned previously, Great Meadows Run and the UNT to Great Meadows Run were, and will continue to be, difficult to sample using the typical ERMN sampling method. Consequently, comparing the BMI communities in those streams to others in the region will be difficult. The fact that the typical sampling method cannot be used in those streams illustrates the habitat degradation that has occurred in those streams. Unfortunately, without human intervention, those streams are likely to remain degraded from a habitat perspective and will consequently be sampled on a rotating basis once a baseline condition of BMI communities has been established (i.e., after a minimum of three years of initial data collection). A similar situation exists at Ice Pond Run which is severely impacted by abandoned mine drainage. Correspondingly, that stream will not be sampled every year after baseline conditions of that BMI community are established. How frequently they will be sampled will be determined in consultation with Connie Ranson.

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